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Abstract

In order to examine fatigue of the knee flexor and extensor muscles and to investigate the characteristics of muscular fatigue in different sports, a Cybex machine was used to measure muscle fatigue and recovery during isokinetic knee flexion and extension. Eighteen baseball players, 12 soccer players and 13 marathon runners were studied. Each subject was tested in the sitting position and made to perform 50 consecutive right knee bends and stretches at maximum strength. This was done 3 times with an interval of 10 min between each series. The peak torque to body weight ratio and the fatigue rate were determined in each case. In all subjects, the peak torque to body weight ratio was higher for extensors than flexors. Over the 3 trials, the fatigue rate of extensors showed little change, while that of flexors had a tendency to increase. In each subject, knee extensors showed a high fatigue rate but a quick recovery, while knee flexors showed a low fatigue rate but a slow recovery. As the marathon runners had the smallest fatigue rates for both flexors and extensors, we concluded that marathon runners had more stamina than baseball players and soccer players.

KEYWORDS: knee flexor and extensor, muscle fatigue, Cybex machine

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Measurement of Fatigue in Knee Flexor and Extensor Muscles

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In order to examine fatigue of the knee flexor and extensor muscles and to investigate the characteristics of muscular fatigue in different sports, a Cybex machine was used to measure muscle fatigue and recovery during isokinetic knee flexion and extension. Eighteen baseball players, 12 soccer players and 13 marathon runners were studied. Each subject was tested in the sitting position and made to perform 50 consecutive right knee bends and stretches at maximum strength. This was done 3 times with an interval of 10 min between each series. The peak torque to body weight ratio and the fatigue rate were determined in each case. In all subjects, the peak torque to body weight ratio was higher for extensors than flexors. Over the 3 trials, the fatigue rate of extensors showed little change, while that of flexors had a tendency to increase. In each subject, knee extensors showed a high fatigue rate but a quick recovery, while knee flexors showed a low fatigue rate but a slow recovery. As the marathon runners had the smallest fatigue rates for both flexors and extensors, we concluded that marathon runners had more stamina than baseball players and soccer players.

Key words: knee flexor and extensor, muscle fatigue, Cybex machine

In various sports, players use their muscles in a manner that leads to muscular fatigue, after which further strenuous exercise can result in muscle damage. One of the most common injuries that arises this way is a "pulled muscle" (muscle strain). Studies (1, 2) have shown that muscle strain most frequently affects the biceps femoris (hamstrings). However, studies on the knee muscles using a Cybex machine have shown that fatigue is greater in the extensor muscles (quadriceps femoris) and less severe in the flexor muscles (hamstrings). This raises the question of why damage occurs more often in the hamstrings, which suffer less fatigue. The purpose of the present study was to examine the pattern of fatigue in the knee flexor and extensor muscles and to investigate the characteristics of muscular fatigue in different sports.

Materials and Methods

Subjects. The subjects were medical students comprising the following: 18 baseball players aged 18 to 24 years (average, 20.6 years) who weighed 48-83 kg (average, 67.1 kg); 12 soccer players aged 19 to 23 years (average, 20.4 years) who weighed 56-68 kg (average, 62.7 kg); and 13 semiprofessional female marathon runners aged 18 to 24 years (average, 20.8 years) who weighed 38-56 kg (average, 46.8 kg) (Table 1).

Methods. The Cybex II (Lumex Inc., NY, USA) machine was used to apply an exercise load and to measure muscle strength and fatigue. Each subject was tested in the sitting position and made to perform 50 consecutive right knee bends and stretches at an angle speed of 180°/sec and at maximum strength. This was done 3 times with an interval of 10 min between each series, during which the subjects rested in a supine position. The peak torque to body weight (PT/BW) ratio and the fatigue rate were determined. The fatigue rate was calculated as follows: (maximum torque of the first 5 knee bends − maximum torque of the last 5 knee bends) ÷ maximum torque of the first 5 bends × 100 (Fig. 1).

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We examined the reproducibility of these measurements in 6 men aged 26 to 37 years (average, 32.7 years) who weighed 64-78 kg (average, 70.7 kg) and were tested 7 times on different days. The coefficient of variations of each parameter was calculated as follows: (standard deviation of the measured value from the mean value ÷ mean value) × 100.

The data were analyzed by performing a 2-way repeated analysis of variance (ANOVA) between knee flexors and extensors for each group.

Table 1 Subjects

	Baseball players	Soccer players	Marathon runners
Sex	male	male	female
Member	18	12	13
Average age	20.6±1.8	20.4±1.2	20.8±2.3
Average weight	67.1±9.9	62.7±3.6	46.8±5.7

Results

Reproducibility. The coefficient of variations of the PT/BW ratio for the knee extensors was 6.6-18.0 % (mean, 9.6%), while that for the flexor muscles was 10.5-29.7% (mean, 17.1%). The coefficient of the fatigue rate for the knee extensor muscles was 2.3-7.7% (mean, 5.1%), while that for the flexor muscles was 4.6 -13.8% (mean, 9.2%). The coefficient of the strength decrement index (SDI) for the knee extensor muscles was 6.8-11.5% (mean, 8.7%), while that for the flexor muscles was 8.1-15.7% (mean, 11.7%) (Table 2).

Peak torque/Body weight ratio. In the baseball players, the mean PT/BW ratio of the knee extensor muscles was 182.6±30.6%, 186.0±21.9% and 177.2±35.9% in the 1st, 2nd and 3rd trials, respectively. In soccer players, the respective values

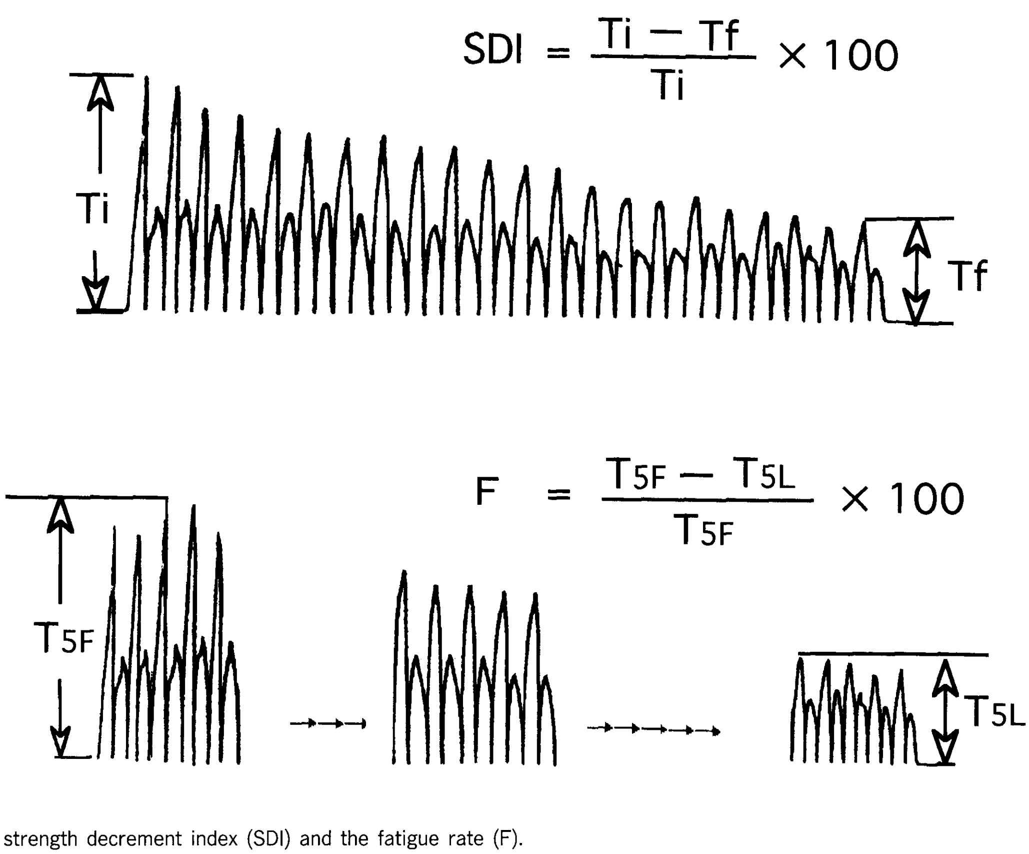

Fig. 1 The strength decrement index (SDI) and the fatigue rate (F).
Typical fatigue curve obtained while using a Cybex II machine. The Y-axis shows muscle torque and the X-axis shows elapsed time. The higher tracing is the quadriceps femoris, and the lower tracing is the hamstring. Ti is the maximum muscle torque, and Tf is the minimum muscle torque. T5F is the maximum muscle torque during the first 5 bends, and T5L is the maximum muscle torque during the last 5 bends.

were 183.7 ± 27.4%, 199.5 ± 22.5% and 192.5 ± 22.1 %, while the values for marathon runners were 132.5 ± 16.5%, 146.8 ± 17.6% and 146.6 ± 16.5%. The values for soccer players were slightly higher compared with those for baseball players, while those for marathon runners were the lowest. Little change was seen in the ratios of subjects from the 3 groups throughout the 3 trials (Fig. 2).

The mean PT/BW ratio for knee flexor muscles in baseball players was 99.4 ± 27.4% (1st trial), 109.4 ± 20.7% (2nd trial) and 103.1 ± 25.2% (3rd trial). The respective values for soccer players were 122.5 ± 14.5%, 130.1 ± 17.5% and 130.3 ± 17.1%, while those for marathon runners were 65.8 ± 10.3%, 72.2 ± 11.1% and 77.6 ± 13.5%. These results show that the values for soccer players were 1.2 times those for baseball players and 1.8 times those for marathon runners. Neither baseball nor soccer players showed a change of values between trials, while the values for marathon runners gradually increased (Fig. 2).

The ratio of knee flexor muscle strength to knee extensor muscle strength (flexor/extensor ratio) was also determined. In the baseball players, the 1st, 2nd and 3rd trials gave values of 53.9 ± 8.7%, 58.0 ± 6.3% and 58.2 ± 8.7%, respectively. The values for the soccer players were 68.2 ± 13.0%, 65.7 ± 10.7% and 69.2 ± 10.5%, respectively, while the marathon runners had values of 50.1 ± 6.6%, 49.4 ± 6.7% and 53.2 ± 7.8%. Thus, the flexor/extensor ratio decreased in order of soccer players, baseball players and marathon runners (Fig. 3).

Table 2 Coefficients of variation

		A	B	C	D	E	F	Mean ± SD
PT/BW	Extensor	8.6	18.0	6.6	8.4	9.0	6.8	9.6±3.9
	Flexor	29.7	14.0	11.0	10.5	12.1	24.8	17.1±7.5
F rate	Extensor	7.7	6.3	5.3	2.3	4.5	4.7	5.1±1.7
	Flexor	13.8	9.1	10.3	12.2	5.2	4.6	9.2±3.4
SDI	Extensor	11.5	7.7	9.4	6.8	8.9	8.0	8.7±1.5
	Flexor	15.7	12.1	13.4	12.5	8.7	8.1	11.7±2.6

All unites, %; PT, peak torque; BW, body weight; F, fatigue; SDI, strength decrement index; SD, standard deviation.

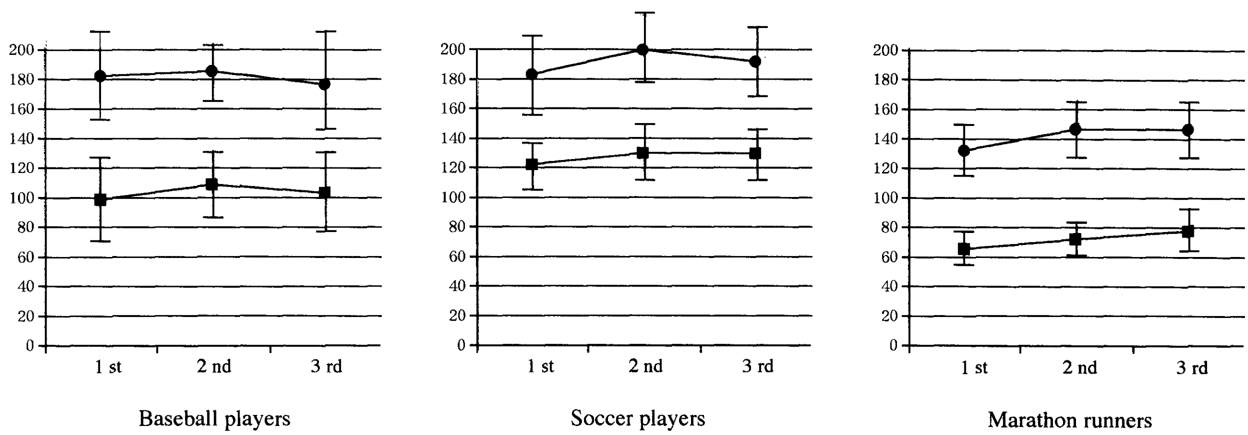

Fig. 2 Peak torque/Body weight (PT/BW) ratio.
●, knee extensor muscles; ■, knee flexor muscles.
All subjects in the 3 groups had stronger knee extensors than knee flexors (0.0001). There was no correlation between the PT/BW ratio and the 3 trials, but the PT/BW ratio for knee flexor muscles in marathon runners tended to increase 3 trials.

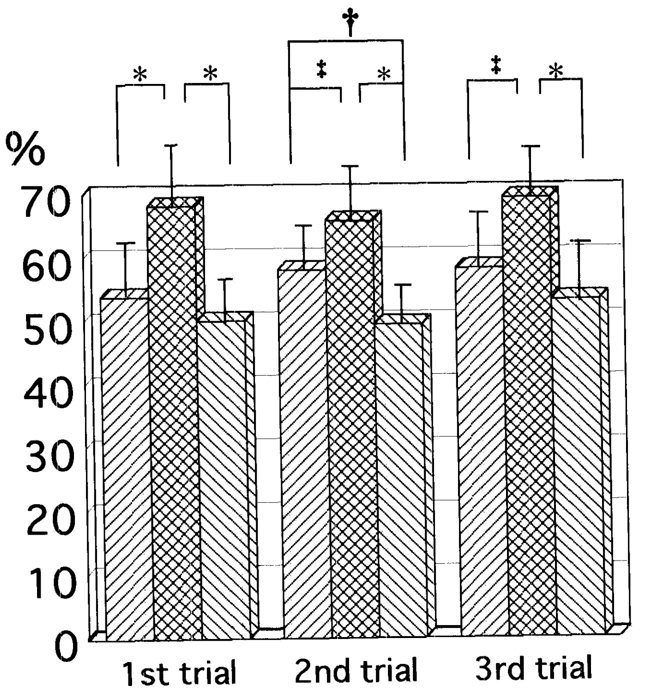

Fig. 3 Flexor/extensor ratio.
▨, baseball players; ⊠, soccer players; ▧, marathon runners.
*, $P < 0.0001$; †, $P < 0.001$; ‡, $P < 0.05$.

Fatigue rate. The fatigue rate of the knee extensor muscles in the 1st, 2nd and 3rd trials performed by the baseball players was 56.1 ± 8.3%, 55.4 ± 9.2% and 55.2 ± 9.3%, respectively. The corresponding values for soccer players were 48.4 ± 8.6%, 48.3 ± 9.5% and 46.4 ± 9.7%, while those for marathon runners were 40.9 ± 9.3%, 42.4 ± 7.3% and 43.0 ± 9.9%. Thus, the runners had the lowest fatigue rate followed by soccer and baseball players in that order (Fig. 4).

The fatigue rate of the knee flexor muscles was respectively 36.0 ± 14.2%, 39.1 ± 9.3% and 41.0 ± 9.3% in the 1st, 2nd and 3rd trials performed by baseball players. The soccer players had corresponding values of 35.3 ± 9.6%, 35.6 ± 9.3% and 40.5 ± 6.5%, while the marathon runners had values of 13.0 ± 17.8%, 14.6 ± 11.7% and 18.6 ± 7.1%. The fatigue rate of the flexor muscles was significantly lower in the marathon runners compared with that of the baseball and soccer players, both of whom had similar values (Fig. 4).

Over the whole series of these trials, the fatigue rate of knee extensor muscles did not change much in all 3 groups. In each trial, the fatigue rate of the knee flexors was lower than that of the extensors. However, the fatigue rate of the flexor muscles had a tendency to increase between the 1st and 3rd trials in all 3 groups.

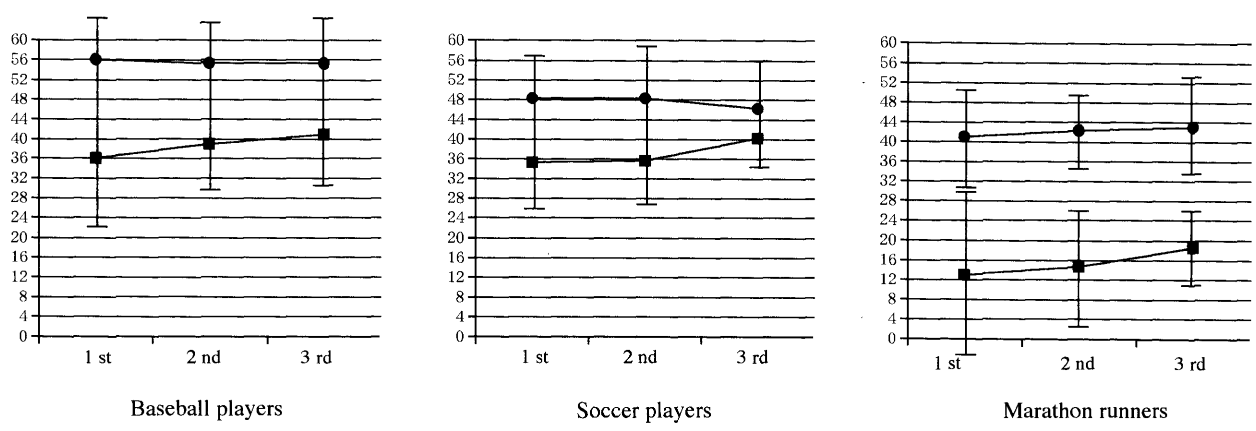

Fig. 4 Fatigue rate of knee extensor and flexor muscles.
●, knee extensors; ■, knee flexors.
In all of the 3 groups, the fatigue rate for the extensor muscles was higher than that for the flexor muscles (baseball players and marathon runners, $P < 0.0001$; soccer players, $P = 0.0016$), and there was no correlation between the fatigue rate and the 3 trials. Though the fatigue rate for the extensor muscles was virtually constant across the 3 trials, the fatigue rate for the flexor muscles tended to increase gradually and showed a significant difference between the 1st and 3rd trials.

Discussion

In 1890, Italian physiologist Mosso (3) was the first to measure muscular fatigue quantitatively. He invented an apparatus for recording the quantity of work performed by a finger, and he named this device the "ergograph". The ergograph was designed to measure fatigue in the digital muscles by reading changes in muscle strength indicated on the recording paper after repeated exertion of the muscles against a fixed weight.

Following Mosso's report, ergographs for the hand and arm were invented by Hough (4) and Hellebrandt *et al.* (5). In 1954, Clarke *et al.* (6) used an ergograph to record changes in muscular tension occurring in supine subjects after repeated flexion and extension of the elbow with weight loading.

The Cybex machine, an instrument designed for performing exercise at a constant speed, was invented during the period from 1965 to 1967 (7, 8). In 1975, Mikanagi *et al.* (9) used the Cybex II machine to create fatigue curves for the knee extensors and flexors. Because these curves were equivalent to Clarke's strength decrement curves, the strength decrement index (SDI) was calculated to study muscular fatigue. The SDI was calculated as follows: $SDI = (Ti - Tf)/Ti \times 100$, where Ti stands for maximum muscle torque and Tf for minimum muscle torque (Fig. 1). The SDI was large for the quadriceps femoris and small for the hamstrings. James *et al.* (10) stated that the changes of strength caused by repeated exercise at a fixed angle speed reflected the changes in output of power. Thus, the muscle fatigue curve corresponds to the output of the Cybex machine.

In 1981, Nicklin *et al.* (11) measured shoulder abduction fatigue using a hand-held dynamometer and devised a fatigue index, which was calculated as the difference between the means of the first 2 and last 2 contractions.

We used a Cybex II machine as Mikanagi *et al.* did, but our method was geared toward assessing both muscular fatigue and recovery. Accordingly, our subjects performed 50 knee bends at the maximum strength. Few of the subjects showed maximum torque at the first bend and minimum torque at the last bend. In a study performed by Sargeant *et al.* in 1981 (12), power output during constant speed cycling reached a peak at 2–3 sec after the start of exercise and declined rapidly. For this reason, we selected the maximum muscle torque among the first 5 bends and the minimum muscle torque among the last 5 bends in order to calculate the fatigue rate with more specific and reliable parameters than those of the SDI. Our subjects performed 3 series of bends and observed a 10-min rest between each trial that corresponded to the rest period in a soccer game. This allowed us to examine the pattern of change in the maximum torque and the fatigue rate after rest, so that we could assess recovery as well as fatigue.

A single series of exercises, as Clarke and Mikanagi *et al.* used in their study, is insufficient for an accurate assessment of muscle fatigue, and our method of using 3 sets of exercises may be more effective for further studies on the characteristics of muscle fatigue and recovery. Our reproducibility test showed that the mean coefficient of variations of individual PT/BW ratio values was 9.6% for the extensor muscles and 17.1% for the flexors, with more scattering in the flexor muscle values. The mean coefficient of the fatigue rate was 5.1% for the extensor muscles and 9.2% for the flexors, and these coefficients were about 3% lower than the mean coefficient of the SDI, which suggested that our method showed better reproducibility and should be used for examining muscular fatigue. Our results also suggested that the physical condition of the subject on the day of study affected the scattering of muscle strength data, but that the fatigue rate did not change much and was less dependent on minor variations in physical condition.

The PT/BW ratio data from each trial showed that all subjects in the 3 groups had stronger knee extensors than knee flexors. The output power ratio of quadriceps femoris to hamstrings was about 3:1 according to Kapandji (13) and 1.7:1 according to Ooi (7). The flexor/extensor ratio (%) was 33.3% in the former study and 58.8% in the latter. Our results agreed fairly well with those of Ooi. Since knee muscles are considered well balanced when the flexor/extensor ratio is 60%, the soccer players were the best balanced subjects according to our results. Throughout the 3 trials, there were few extensor muscle changes in the 3 groups of subjects, and peak torque was recovered after the 10-min rest. No change of the PT/BW ratio was seen in the flexor muscles of the baseball and soccer players, but a gradual increase was seen in those of the marathon runners. This result suggests that marathon runners may display more muscle strength when a load is added.

In each trial, the fatigue rate of the extensor muscles of all subjects in the 3 groups was higher than that of the flexor muscles. This result agrees with the findings of Mikanagi *et al.* (9). Throughout all 3 trials, few changes were seen in the fatigue rate of the extensor muscles, while an increase was seen in the fatigue rate of the flexor muscles. This suggests that 10 min of rest allowed for complete recovery of the extensor muscles, but not for the flexor muscles, leading to increased fatigue during subsequent trials. That is, the extensor muscles had a high fatigue rate but a quick recovery, while the flexor muscles had a lower fatigue rate but a delayed recovery.

All the marathon runners were women, so their muscle strength was naturally lower than that of the baseball and soccer players. However, during the 3 series of exercises, the flexor muscle PT/BW ratio of the marathon runners increased despite accumulated fatigue. Moreover, the fatigue rate of the runners was smaller than that of the baseball and soccer players, and their flexor muscle fatigue rate was less than half that of the other subjects, suggesting that the runners had better endurance. These results accorded with the generally known facts that marathon runners have less muscle strength than sprinters but are slower to fatigue. Accordingly, our method of measuring fatigue in knee flexor and extensor muscles seems to be reasonably accurate.

Studies on lactic acid (14) have shown that it can be removed from the blood more quickly by performing light exercise during recovery after strenuous exercise than by observing complete rest. We will continue to study rest and recovery from fatigue to determine the most effective method of resting in sports like soccer and baseball.

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